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(54) Method for moiré-free color halftoning using non-orthogonal cluster screens

(57) The invention provides methods for using single-cell non-orthogonal cluster screens to satisfy the moiré-free conditions for color halftoning. The invention also provides methods that combine single-cell non-orthogonal cluster screens and line screens for moiré-free color halftoning. Particularly, the selection of these single-cell halftone screens is determined by satisfying moiré-free conditions provided in the respective spatial or frequency equations.

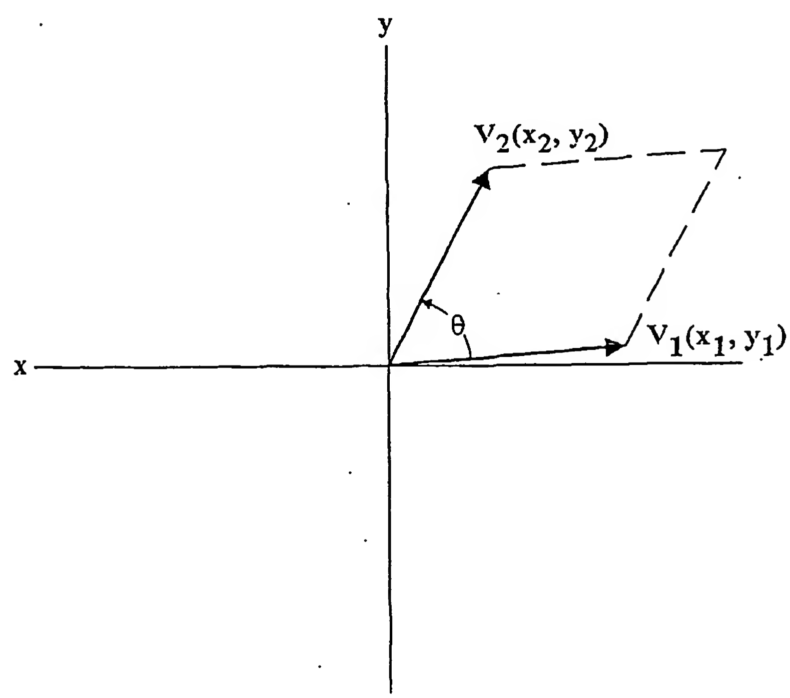

FIG. 1

the raster structure. Therefore, the shape and center location varies from one halftone dot to another. Consequently, additional interference or moiré between the screen frequencies and the raster frequency can occur. In another approach, U.S. Patent 5,371,612 discloses a moiré prevention method to determine screen angles and sizes that is usable solely for square-shaped, halftone screens.

SUMMARY OF THE INVENTION

[0009] This invention provides systems and methods that combine single-cell non-orthogonal cluster screens in different color separations for substantially moiré-free color halftoning.

[0010] This invention separately provides systems and methods that combine single-cell non-orthogonal cluster screens and line screens in different color separations for substantially moiré-free color halftoning.

[0011] In various exemplary embodiments, the combination of non-orthogonal single-cell halftone screens is determined by satisfying moiré-free conditions in spatial or frequency space for the functions that define the non-orthogonal single cell halftone screens.

[0012] These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of various exemplary embodiments of the systems and methods according to this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Various exemplary embodiments of this invention will be described in detail, with reference to the following figures, wherein:

Fig. 1 is a two-dimensional spatial vector representation of a single-cell halftone screen;
Fig. 2 is a frequency vector representation of the halftone screen of Fig. 1;
Fig. 3 illustrates a frequency domain representation of three single-cell halftone screens;
Fig. 4 illustrates an exemplary frequency domain representation of Fig. 3 constrained to satisfy moiré-free conditions;
Fig. 5 is a flowchart outlining one exemplary embodiment of a method for determining a combination of non-orthogonal single-cell halftone screens according to this invention that will provide at least substantially moiré-free color halftoning;
Fig. 6 is a block diagram of a system usable to generate a combination of non-orthogonal single-cell halftone screens according to this invention usable for substantially moiré-free color printing.
Fig. 7 illustrates a two-dimensional spatial vector representation of a line screen;
Fig. 8 illustrates a frequency domain representation of the line screens shown in Fig. 7;
Fig. 9 illustrates a frequency domain representation of the non-zero frequency vectors for three line screens;
Fig. 10 illustrates a frequency domain representation of a combination of two single-cell halftone screens and a line screen according to an exemplary embodiment of this invention;
Fig. 11 is a flowchart outlining one exemplary embodiment of a method for determining a combination of non-orthogonal cluster screens and line screens according to this invention that provide at least substantially moiré-free color halftoning;
Fig. 12 illustrates a spatial domain representation of a combination of non-orthogonal parallelogram cells and line screens according to an exemplary embodiment of this invention; and
Fig. 13 is a block diagram of an exemplary halftone printing system that uses an exemplary embodiment of a combination of halftone screens according to this invention to form a substantially moiré-free halftone image.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0014] It is well known that color halftone printers are susceptible to moiré patterns if the halftone dots of a given color separation spatially overlap the halftone dots of another color separation. Therefore, there has been a long-felt need for convenient systems and methods for determining the spatial and angular positioning of the halftone dots necessary to avoid moiré patterns.

[0015] It should be appreciated that, according to this invention, a single-cell halftone dot does not necessarily have to be square in shape. In fact, in view of the following teachings according to this invention, it is beneficial to consider a more general single-cell halftone dot shape other than a square, such as, for example, a non-orthogonal parallelogram. It should be further appreciated, however, that a square can be considered to be a subset of the more general class of parallelograms. Therefore, the following discussion regarding exemplary non-orthogonal parallelograms can be equally applied to square halftone dots, as desired.

[0016] To this end, as shown in Fig. 1, a single-cell halftone dot can be an arbitrarily shaped parallelogram and can

$$f_{x_2} = \frac{-y_2}{A}, \tag{4c}$$

and

$$f_{y_2} = \frac{x_2}{A}. \tag{4d}$$

[0019] Therefore, Eqs. (4a) - (4d) express the frequency-to-spatial-component relationship for a cell defined by the spatial vectors $\mathbf{V}_1$ and $\mathbf{V}_2$. Although, in general, the frequency components, f_{x_1}, f_{y_1}, f_{x_2}, and f_{y_2} are real numbers, they are also rational numbers completely defined by the four integer coordinate values, x_1, y_1, x_2 and y_2. Since Eqs. (4a) - (4d) describe a corresponding "mapping" of the frequency components to the spatial components, it should be appreciated that any analysis of the moiré-free conditions in the frequency domain can be easily translated into a spatial domain specification. It should be appreciated that, while the above equations are developed in relation to a non-orthogonal single-cell halftone dot having a parallelogram-like shape, it is apparent that the above equations may suitably describe other non-parallelogram shaped dots, for example, squares, rectangles, triangles, ellipses, etc., without departing from the spirit or scope of this invention.

[0020] To this end, Fig. 3 is an exemplary vector representation in the frequency domain of three parallelogram halftone cells in the spatial domain used in the cyan (c), magenta (m), and black (k) color separations, respectively. As shown in Figs. 1 and 2, the cyan, magenta, and black parallelogram single-cell halftone screens can be represented by pairs of spatial vectors $\mathbf{V}_{1_c}$ and $\mathbf{V}_{2_c}$, $\mathbf{V}_{1_m}$ and $\mathbf{V}_{2_m}$, and $\mathbf{V}_{1_k}$ and $\mathbf{V}_{2_k}$, respectively, corresponding to the frequency vector pairs $\mathbf{F}_{1_c}$ and $\mathbf{F}_{2_c}$, $\mathbf{F}_{1_m}$ and $\mathbf{F}_{2_m}$, and $\mathbf{F}_{1_k}$ and $\mathbf{F}_{2_k}$, respectively.

[0021] From Fig. 3, it is apparent that, to substantially reduce the likelihood of any three-color moiré occurring in any image printed using three single-cell halftone screens, the frequency vectors of the three color separations, for example, cyan, magenta and black, should satisfy the following vector equations:

$$F_{c_1} + F_{m_1} + F_{k_1} = 0, \tag{5a}$$

and

$$F_{c_2} + F_{m_2} + F_{k_2} = 0, \tag{5b}$$

[0022] Fig. 4 is a vector diagram illustrating the exemplary moiré-free vector relationships defined in Eqs. (5a) and (5b). It should be appreciated from frequency analysis that, for any frequency vector $\mathbf{F}(f_x, f_y)$, there is always a conjugate frequency vector $\mathbf{F}(-f_x, -f_y)$, hereafter denoted as $-\mathbf{F}$. Therefore, it should also be appreciated that the two vectors $\mathbf{F}$ and $-\mathbf{F}$ are exchangeable. Further, it should be appreciated that the arbitrary indices 1 and 2 may be exchanged between the two frequency vectors $\mathbf{F}_1$ and $\mathbf{F}_2$ in each color separation. Thus, Eqs. (5a) and (5b) can be considered as a general description for the three-color moiré-free condition, which can include all other possible combinations, such as, for example, the following Eqs. (5c) and (Sd):

$$F_{c_2} + F_{m_1} - F_{k_1} = 0, \tag{5c}$$

and

$$F_{c_1} - F_{m_2} - F_{k_2} = 0, \tag{5d}$$

[0023] Using the scalar components of the frequency representation and Eqs. (4a) - (4d) and the above moiré-free conditions, Eqs. (5a) and (5b) can be translated into the following spatial vector equations, Eqs. (6a) and (6b), or scalar equations, Eqs. (7a) - (7d):

$$A_k = |x_{k1}y_{k2} - x_{k2}y_{k1}|. \tag{8g}$$

Eqs. (8a) - (8d) specify the spatial vector component relationships for a moiré-free condition and can be used, as described below, to determine the sizes and angles for corresponding halftone cells.

[0024] Although the analysis provided above assumes that the spatial coordinates x and y are integers, the moiré-free condition given by Eqs. (8a) - (8d) is true even if x and y are arbitrary real numbers. For example, a classical solution can be found if all single-cell halftone screens are square-shaped and the areas of these squares are the same, i.e., $A_c = A_m = A_k = a^2$, where a is the length of the side of the square. By setting a cyan halftone screen at 15°, a magenta halftone screen at 75° and a black halftone screen at 45°, the six spatial vectors, which satisfy the moiré-free condition specified by Eqs. (8a) - (8d), are:

$$V_{c_1} :(a\cdot\cos15°,-a\cdot\sin15°),\ V_{c_2} :(a\cdot\sin15°,a\cdot\cos15°), \tag{9a}$$

$$V_{m_1} :(-a\cdot\cos75°,-a\cdot\sin75°),\ V_{m_2} :(-a\cdot\sin75°,-a\cdot\cos75°), \tag{9b}$$

$$V_{k_1} :(-a\cdot\cos45°,-a\cdot\sin75°),\ V_{k_2} :(a\cdot\sin45°,-a\cdot\cos45°), \tag{9c}$$

It is apparent from Eqs. (9a) - (9c) that the spatial vectors of the cyan ($\mathbf{V}_{c1}$, $\mathbf{V}_{c2}$) and magenta ($\mathbf{V}_{m1}$, $\mathbf{V}_{m2}$) halftone screens of this classical solution do not correspond to rational numbers and, therefore, the classical moiré-free solution cannot be accurately implemented in conventional digital halftoning. Although halftone screens with multiple clusters can use rational numbers for specifying spatial vectors, this approach results in some clusters having centers that do not lie directly on addressable points, i.e., do not lie on the pixel positions defined by the raster structure. Thus, the shape and center location varies from one cluster to another. Therefore, additional interference or moiré between screen frequencies and the raster frequency may occur. Given that, for the moiré-free condition, there are only four equations, Eqs. (8a) - (8d), with twelve variables, according to the three color separations of cyan, magenta, and black, for example, and four spatial coordinates for each color of the color separations, the set of solutions become infinite if x and y are arbitrary real numbers.

[0025] However, if the spatial coordinates, x and y, are restricted to the set of integers, the set of solutions becomes finite and can be practically handled. In particular, for most digital halftoning applications, the number of possible sizes for each single-cell screen is generally less than a hundred or so. As a result, all possible solutions satisfying the moiré-free condition given by Eqs. (8a) - (8d) can be readily searched. Unfortunately, it is apparent that very few solutions can be found if all clusters are limited to solely square-shaped, integer-specified cells.

[0026] However, the range of possible solutions can be greatly increased by applying non-orthogonal or, such as, for example, parallelogram-shaped, single-cell halftone screens. For example, the following spatial vectors describe three parallelogram halftone cells in the cyan, magenta and black color separations:

$$V_{c_1}: (4, -2), \qquad V_{c_2} : (1,7), \tag{10a}$$

$$V_{m_1}: (-1,7), \qquad V_{m_2}: (-4, -2), \tag{10b}$$

$$V_{k_1}: (-3, -5), \qquad V_{k_2}: (3, -5). \tag{10c}$$

[0027] It should be appreciated that the spatial domain representation of the above vectors of Eqs. (10a) - (10c) are very similar to the classical solution for a 600 x 1200 dpi printer:

Cyan: -75.96º, 164.9 lpi and 15.95º, 145.6 lpi; (11a)

tially moiré-free non-orthogonal halftone cluster screen generating system 300 may contain its own individual memory or controller.

[0038] In various exemplary embodiments, the non-orthogonal cluster cell locator circuit, routine or agent 330 searches and locates non-orthogonal cluster cells according to Eqs. (8a) - (8d). In various exemplary embodiments, the non-orthogonal cluster cell locator circuit, routine or agent 340 stores the located non-orthogonal cluster cells in the located non-orthogonal cluster cells segment 331 under control of the controller 320. The cluster cell remover circuit, routine or agent 350 removes cluster cells located by the non-orthogonal cluster cell locator 340 from the cluster cells stored in the located non-orthogonal cluster cells segment 331 based on the primary constraints stored in the primary constraints segment 333.

[0039] Alternatively, in various other exemplary embodiments, the non-orthogonal cluster cell locator circuit, routine or agent 340 supplies the located non-orthogonal cluster cells, whether under control of the controller 320 or not, directly to the cluster cell remover circuit, routine or agent 350. In this case, the cluster cell remover, routine or agent 350 determines which located non-orthogonal cluster cells satisfy the primary constraints stored in the primary constraints segment 333. Then, under control of the controller 320, the cluster cell remover circuit, routine or agent 350 either stores those located non-orthogonal cluster cells that meet the primary constraints stored in the located non-orthogonal cluster cells segment 331 or supplies them directly to the combination identifier circuit, routine or agent 360..

[0040] The combination identifier circuit, routine, or agent 360, under control of the controller 320, identifies combinations of located cluster cells that satisfy the moiré-free conditions described herein. For example, in various exemplary embodiments, the combination identifier circuit, routine or agent 360 identifies those combinations that satisfy Eqs. (8a) - (8d). In various other exemplary embodiments, the combination identifier circuit, routine or agent 360 identifies those combinations that satisfy the equations outlined below for combinations of cluster and line screens. The identified combinations may be determined according to the different color separations of the halftone screens. In various other exemplary embodiments, the combination identifier circuit, routine or agent 360 stores the identified combinations of the remaining located non-orthogonal cluster cells in the identified combinations segment 337, under control of the controller 320. The combination remover circuit, routine or agent 370, under control of the controller 320, removes certain combinations that do not satisfy the additional constraints, if any, that may be stored in the additional constraints segment 335.

[0041] Alternatively, in various other exemplary embodiments, if any additional constraints are provided by the user, the combination identifier circuit, routine or agent 360 directly supplies the identified combinations to the combination remover circuit, routine or agent 370.

[0042] In this case, if additional constraints are provided, the combination remover circuit, routine or agent 370 determines which identified combinations satisfy the additional constraints. Then, under control of the controller 320, the combination remover circuit, routine or agent 370 either stores the remaining identified combinations that meet the additional constraints stored in the identified combinations segment 337, or provides the remaining identified combinations to the user, or, if provided, to the combination selector circuit, routine or agent 390.

[0043] The identified combinations stored in the identified combinations segment 337 are then provided to the user to allow the user to select one of the identified combinations to be used to generate substantially moiré-free halftone images. Alternatively, in other various exemplary embodiments where the combination selector circuit, routine or agent 390 is implemented, the identified combinations are provided to the combination selector circuit, routine or agent 390, which selects one of the identified combinations to be used to generate substantially moiré-free halftone images. In either case, the selected combination is then stored in the selected combinations segment 339.

[0044] It should be further appreciated that any of the elements 310-390 of the substantially moiré-free non-orthogonal halftone cluster screen generating system 300 may access data and/or signals input from the one or more input devices 410 through the input/output interface 310. Similarly, any of the elements 310-390 of the substantially moiré-free non-orthogonal halftone cluster screen generating system 300 may output data and/or signals to the display device 400.

[0045] As shown in Fig. 6, the image display device 400 and the user input device 410 are connected over links 402 and 412, respectively, to the input/output interface 310 which is connected to the moiré-free non-orthogonal halftone cluster screen generating system 300 via the control/data bus 380. The links 402 and 412 may be any known or later developed system or devices for transmitting an electronic image or electronic information/data to and from the display device 400 to the input/output interface 310, or to and from the user input device to the input/output interface 310. The image display device 400 displays electronic image data generated by or for the moiré-free non-orthogonal halftone cluster screen generating system 300. The one or more user input devices 410 control the electronic image generated by the display device 400 and/or control the operation of the moiré-free non-orthogonal halftone cluster screen generating system 300. The image display device 400 and/or user input device 410 can be integrated with the moiré-free non-orthogonal halftone cluster screen generating system 300.

[0046] The above exemplary procedures for generating moiré-free non-orthogonal cell halftone screens, as illustrated in Figs. 1-6, can be further supplemented by combining the above discussed non-orthogonal cell halftone screens

$$F_{c_2} + F_{m_2} + F_{k_2} = 0 \tag{15}$$

It is apparent that the above-outlined moiré-free condition in Eq. (15) is unchanged even if several single-cell cluster screens are replaced by line screens.

[0050] Further, the moiré-free condition specified by the vector equation, Eq.(15), can also be expressed by two scalar equations, which are identical to Eqs. (8c) and (8d) and rewritten below as:

$$A_m A_k x_{c2} + A_c A_k x_{m2} + A_c A_m x_{k2} = 0, \tag{8c}$$

and

$$A_m A_k y_{c2} + A_c A_k y_{m2} + A_c A_m y_{k2} = 0, \quad \text{8d)}$$

where the areas A_c, A_m and A_k are given by Eqs. (8e) - (8g).

[0051] In the above-outlined discussion, the line screen defined by the two vectors, $\mathbf{V}_1(W,0)$ and $\mathbf{V}_2(S,1)$, represents a set of line screens, which are tilted from the y-axis. It should be appreciated that another set of line screens, which are tilted from the x-axis, can be defined by two vectors, $\mathbf{V}_1(0,W)$ and $\mathbf{V}_2(1, S)$ and can be equally applied in the above-outlined equations.

[0052] It is readily apparent that the moiré-free condition, specified by the vector equation, Eq. (15), and the two scalar equations, Eqs. (8c) and (8d), can be applied to any combination of non-orthogonal cluster screens that includes one or more line screens.

[0053] Fig. 9 provides, for example, a vector diagram of three line screens in the frequency domain, corresponding to the $\mathbf{F}_{c2}$, $\mathbf{F}_{m2}$, and $\mathbf{F}_{k2}$ vectors of Eq. (15). It is apparent that, similarly to the analysis previously discussed for non-orthogonal cluster screens, the line screens and non-orthogonal cluster screens corresponding to the solutions for Eqs. (15), (8c) and (8d) can also be used to provide moiré-free halftoning.

[0054] Fig. 10 illustrates, in the frequency domain, a moiré-free condition corresponding to Eq. (15) for an exemplary combination of a line screen in a cyan ($\mathbf{F}_{c_1}$ and $\mathbf{F}_{c2}$) color separation and two cluster screens in the magenta ($\mathbf{F}_{m_1}$ and $\mathbf{F}_{m2}$) and black ($\mathbf{F}_{k_1}$ and $\mathbf{F}_{k2}$) color separations, respectively. The exemplary arrangement of line screen and cluster screens frequency vectors in Fig. 10 can be contrasted to Fig. 4, which illustrates in the frequency domain the exemplary moire-free conditions for the all-cluster screen case.

[0055] It is apparent that even if only one line screen is combined with two other parallelogram cluster screens, the moiré-free conditions can be reduced to one vector equation, Eq. (15). Therefore, the combination of line screens and non-orthogonal cluster screens provides extra degrees of freedom in selecting suitable screen solutions.

[0056] Fig. 11 is a flowchart outlining an exemplary embodiment of a process, according to this invention, for combining non-orthogonal single-cell cluster screens with line screens to form substantially moiré-free halftoning.

[0057] Beginning in step S400, control proceeds to step S410, where all non-orthogonal halftone cluster cells having integer values for x_1, y_1, x_2 and y_2 are found. As line screens can be treated as special cases of non-orthogonal parallelograms, i.e., degenerate parallelograms, all possible line screens solutions can also be obtained from the non-orthogonal halftone cluster cells found in step S410. Of course, for non-orthogonal cells, the analysis includes calculation on both frequency components (e.g., $\mathbf{F}_1$ and $\mathbf{F}_2$). In step S420, those non-orthogonal halftone cluster cells found in step S410 that do not satisfy one or more primary constraints are removed from the solutions set. In various exemplary embodiments, these primary constraints can include requiring a non-orthogonal halftone cluster cell to have both diagonals longer than all the sides of that non-orthogonal halftone cluster cell. Next, in step S430, any combinations of non-orthogonal halftone cluster screens and line screens that satisfy integer equations (8c) and (8d) are identified. Control then continues to step S440.

[0058] In step S440, a determination is made whether any additional constraints are to be applied. Such additional constraints can contain, for example, frequency ranges, multi-color moiré constraints, printer limitations, etc. If no additional constraints are identified, control jumps to step S460. Otherwise, if the identified combinations are required to meet at least one additional constraint, control continues to step S450.

[0059] In step S450, those identified combinations of non-orthogonal cells that do not meet the additional constraints are removed from the identified combinations of non-orthogonal cells. Then, in step S460, one of the remaining combinations of non-orthogonal halftone cluster cells and line screen cells is selected and each of the various halftone screens is associated with each of the color separations. The method then ends in step S470. It is apparent that the above-outlined method may be readily implemented in software that can be used in a variety of hardware systems.

540 to print a halftone version of the image data received from the image data source 600. Because the image processor 520 used the non-orthogonal halftone screens selected according to this invention to generate the halftoned raster data, the resulting halftone image is substantially moiré-free. The image forming engine 540 may be a laser or ink-jet printer, a digital copier, a facsimile device, a computer with a built-in printer, or any other device that is capable of producing a hard copy image output based on halftone raster data.

[0069] It should be appreciated that the image processor 520 may be one or more general or special purpose computers, programmed microprocessors or microcontrollers and peripheral integrated circuit elements, ASIC or other logic circuits such as discrete element circuits, programmable logic devices such as PLD, PLA, FPGA or the like.

[0070] It should be also appreciated that, while the electronic image data can be generated at the time of printing an image from an original physical document, the electronic image data could have been generated at any time in the past. Moreover, the electronic image data need not have been generated from the original physical document, but could have been created from scratch electronically. The image data source 600 is thus any known or later developed system or device for generating, storing and/or transmitting the electronic image data to the color halftoning printing system 500.

[0071] While the color halftoning printing system 500 shown in Fig. 13 contains several distinct components, it should be appreciated that each of these components may be combined in a device or system that performs all the functions of the individual components. Similarly, it is appreciated that the color halftoning printing system 500 may contain less than all the components illustrated in Fig. 13 without departing from the spirit and scope of this invention. For example, a color halftoning printing system may also contain a monitor, if desired. Also, the image processor 520 may possess supporting hardware or devices such as additional memory, a communication path, I/O devices, etc., without departing from the spirit and scope of this invention. Accordingly, the systems and methods according to this invention allow more degrees of freedom for moiré-free color halftoning than were previously available when selecting the cluster and/or line screens to be used when halftoning the various color separations.

[0072] Though the above exemplary procedures describe solution sets according to the moiré-free equations described above, it is apparent that equally desirable solution sets can be found by replacing the right hand side of the moiré-free equations with an arbitrarily small number or by suitably altering the quantity or expression of the parameters of the moiré-free equations without departing from the spirit and scope of this invention. Further, while the exemplary embodiments describe solutions for the color separations of cyan, magenta, and black, other colors or combinations of colors, as desired, can be substituted. Also, more or less than three color separations can be utilized as desired.

[0073] Further, while the exemplary embodiments refer to solution sets as principally containing non-orthogonal, parallelogram-shaped cluster cells, it should be appreciated that the exemplary embodiments according to this invention can also be applied to non-parallelogram shaped dots. For example, squares, rectangles, triangles, ellipses, oblate or prolate shapes, trapezoidal shapes or the like, where the outer boundary of the respective shape is substantially contained within the angles formed by the representative halftone cell vectors, can be used. Therefore, it should be appreciated that various exemplary embodiments of this invention can suitably generate and/or use combinations of various at least substantially moiré-free cluster cells whose halftone dot boundaries can be substantially defined by the respective spatial or frequency domain vectors. It is evident that many alternatives, modifications, or variations of the cell types and procedures for combining various cell types for satisfying the moiré-free conditions are apparent to those skilled in the art. Accordingly, various changes may be made without departing from the spirit and scope of the invention.

Claims

1. A method of generating a plurality of non-orthogonal halftone screens for substantially moiré-free color halftoning, comprising:

   locating non-orthogonal halftone cells substantially specified by two spatial vectors (x_{n_1}, y_{n_1}) and (x_{n_2}, y_{n_2}) that substantially form a non-orthogonal halftone cell, where, x_{n_1}, y_{n_1} and x_{n_2}, y_{n_2} are substantially integer valued;
   identifying combinations of the located non-orthogonal halftone cells, suitable for tiling an image plane, of at least three of the located non-orthogonal halftone cells, where the spatial vectors of the identified combinations satisfy:

$$A_bA_cx_{a_1} + A_cA_ax_{b_1} + A_aA_bx_{c_1} \cong 0,$$

$$A_bA_cy_{a_1} + A_cA_ay_{b_1} + A_aA_by_{c_1} \cong 0,$$

identifying combinations of the located non-orthogonal halftone cells and at least one of the located halftone line screens, suitable for tiling an image plane, of at least three of the located non-orthogonal halftone cells and line screens where the spatial vectors of the identified combinations satisfy:

$$A_b A_c x_{a_2} + A_c A_a x_{b_2} + A_a A_b x_{c_2} \cong 0,$$

and

$$A_b A_c y_{a_2} + A_c A_a y_{b_2} + A_a A_b y_{c_2} \cong 0,$$

where,

the subscripts 1 and 2 are arbitrary and interchangeable;
n = a, b, c,
m = a, b, c, where,
a, b, c are arbitrary color indices; and

$$A_n = |x_{n_1} y_{n_2} - x_{n_2} y_{n_1}|;$$

selecting one of the identified combinations; and
associating each non-orthogonal halftone cell or line screen of the selected identified combination with one or more color separations of a color halftone printer.

8. An apparatus for generating non-orthogonal halftone screens for substantially moiré-free color halftoning, comprising:

a non-orthogonal halftone cell locating circuit, routine or agent that locates substantially non-orthogonal halftone cells that are substantially specified by two spatial vectors (x_{n1}, y_{n1}) and (x_{n2}, y_{n2}), where, x_{n1}, y_{n1} and x_{n2}, y_{n2} are substantially integer valued;,
a non-orthogonal halftone cell combination identifying circuit, routine or agent that identifies combinations, suitable for tiling an image plane, of at least three of the located non-orthogonal halftone cells where the spatial vectors of the identified combinations satisfy:

$$A_b A_c x_{a_1} + A_c A_a x_{b_1} + A_a A_b x_{c_1} \cong 0,$$

$$A_b A_c y_{a_1} + A_c A_a y_{b_1} + A_a A_b y_{c_1} \cong 0,$$

$$A_b A_c x_{a_2} + A_c A_a x_{b_2} + A_a A_b x_{c_2} \cong 0,$$

and

$$A_b A_c y_{a_2} + A_c A_a y_{b_2} + A_a A_b y_{c_2} \cong 0,$$

where,

the subscripts 1 and 2 are arbitrary and interchangeable,
n = a, b, c, where,
a, b, c are arbitrary color indices; and

$$A_n = |x_{n_1} y_{n_2} - x_{n_2} y_{n_1}|;$$

or

$$y_{m_1} = 0 \text{ and } y_{m_2} = 1;$$

the spatial vectors of the combinations of located non-orthogonal halftone cells and line screens satisfy:

$$A_b A_c x_{a_2} + A_c A_a x_{b_2} + A_a A_b x_{c_2} \cong 0,$$

and

$$A_b A_c y_{a_2} + A_c A_a y_{b_2} + A_a A_b y_{c_2} \cong 0,$$

where,

the subscripts 1 and 2 are arbitrary and interchangeable, n = a, b, c, m = a, b, c; where
a, b, c are arbitrary color indices; and

$$A_n = |x_{n_1} y_{n_2} - x_{n_2} y_{n_1}|;$$

selecting one of the identified combinations; and
associating each non-orthogonal halftone cell or line screen of the selected identified combination with one or more color separations of a color image generating system; and
forming an image on an image recording medium using the halftone image data.

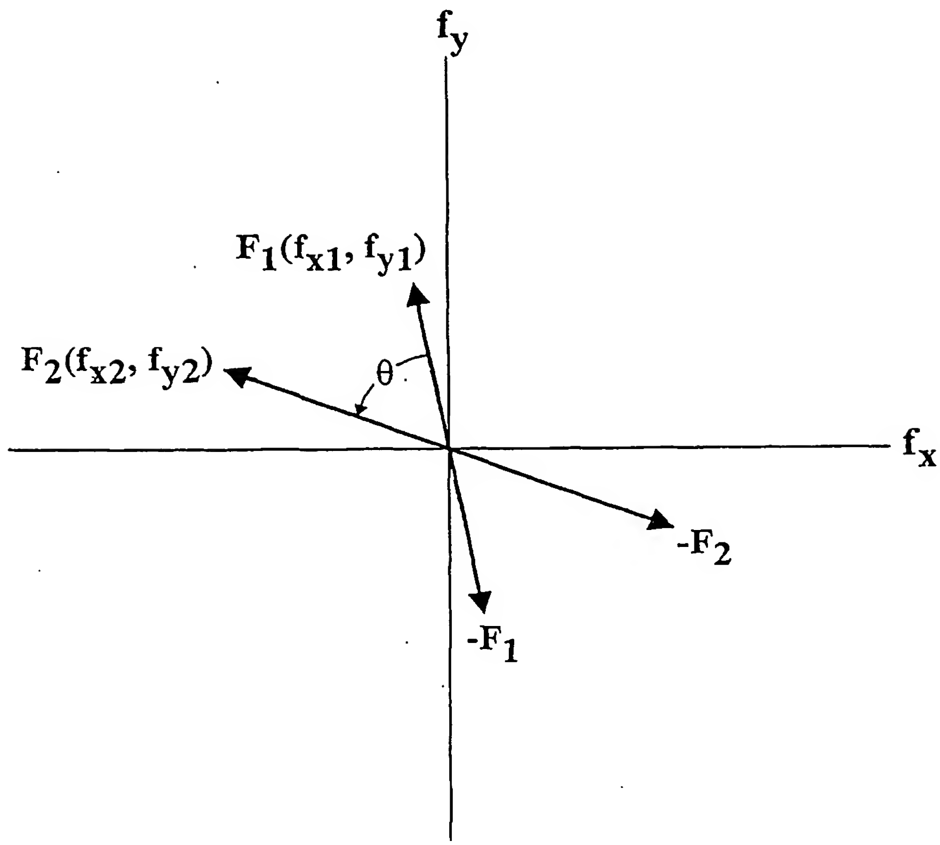

FIG. 2

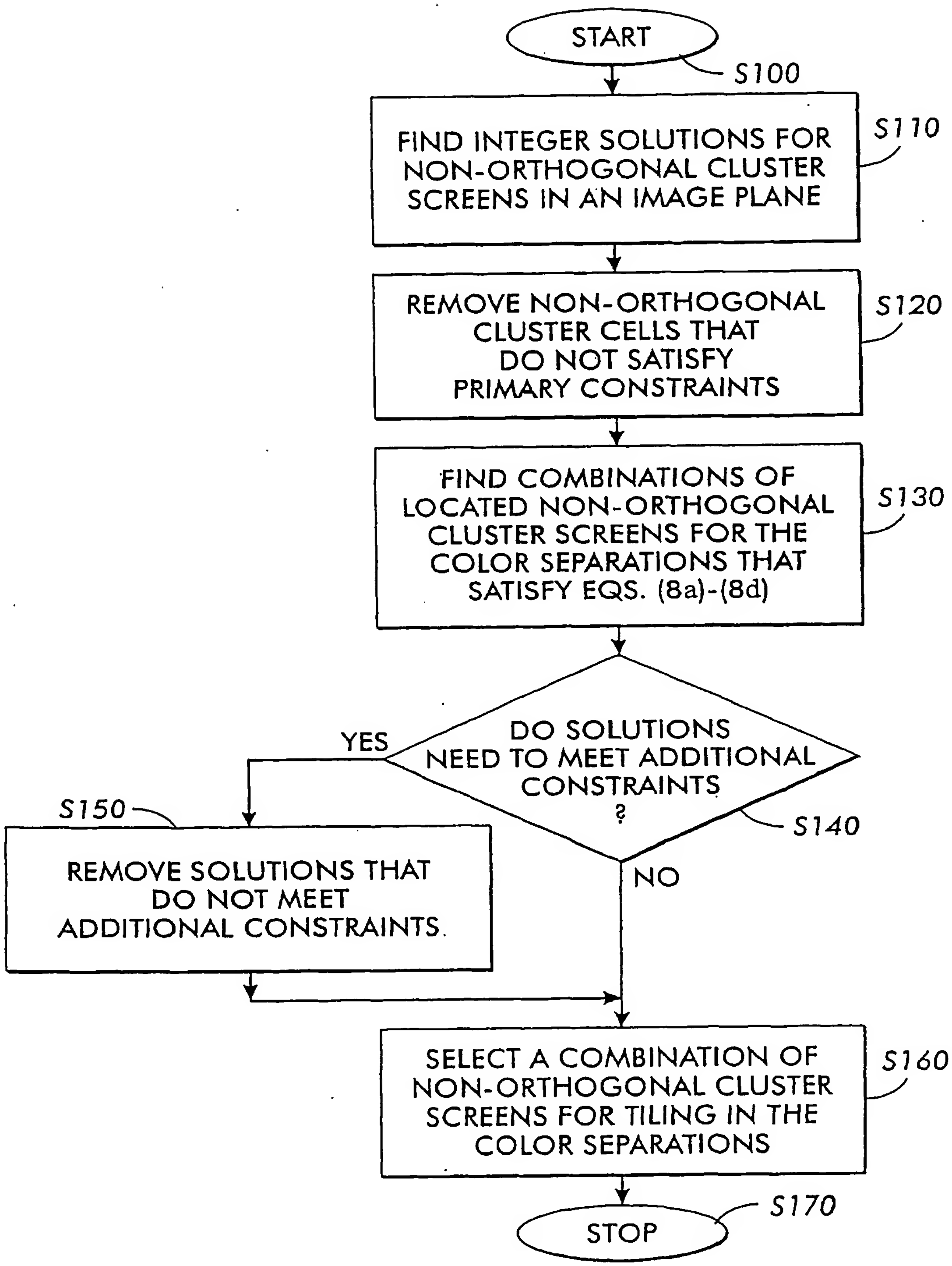
START
S100
FIND INTEGER SOLUTIONS FOR NON-ORTHOGONAL CLUSTER SCREENS IN AN IMAGE PLANE
S110
REMOVE NON-ORTHOGONAL CLUSTER CELLS THAT DO NOT SATISFY PRIMARY CONSTRAINTS
S120
FIND COMBINATIONS OF LOCATED NON-ORTHOGONAL CLUSTER SCREENS FOR THE COLOR SEPARATIONS THAT SATISFY EQS. (8a)-(8d)
S130
DO SOLUTIONS NEED TO MEET ADDITIONAL CONSTRAINTS ?
S140
YES
NO
S150
REMOVE SOLUTIONS THAT DO NOT MEET ADDITIONAL CONSTRAINTS.
SELECT A COMBINATION OF NON-ORTHOGONAL CLUSTER SCREENS FOR TILING IN THE COLOR SEPARATIONS
S160
STOP
S170

FIG. 5

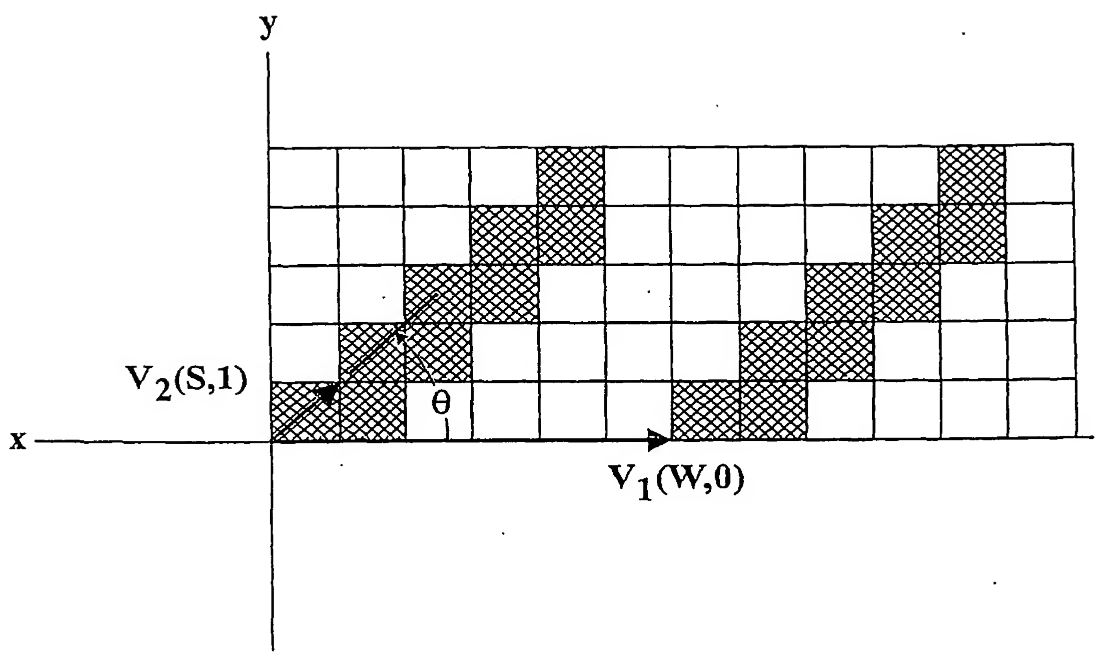

FIG. 7

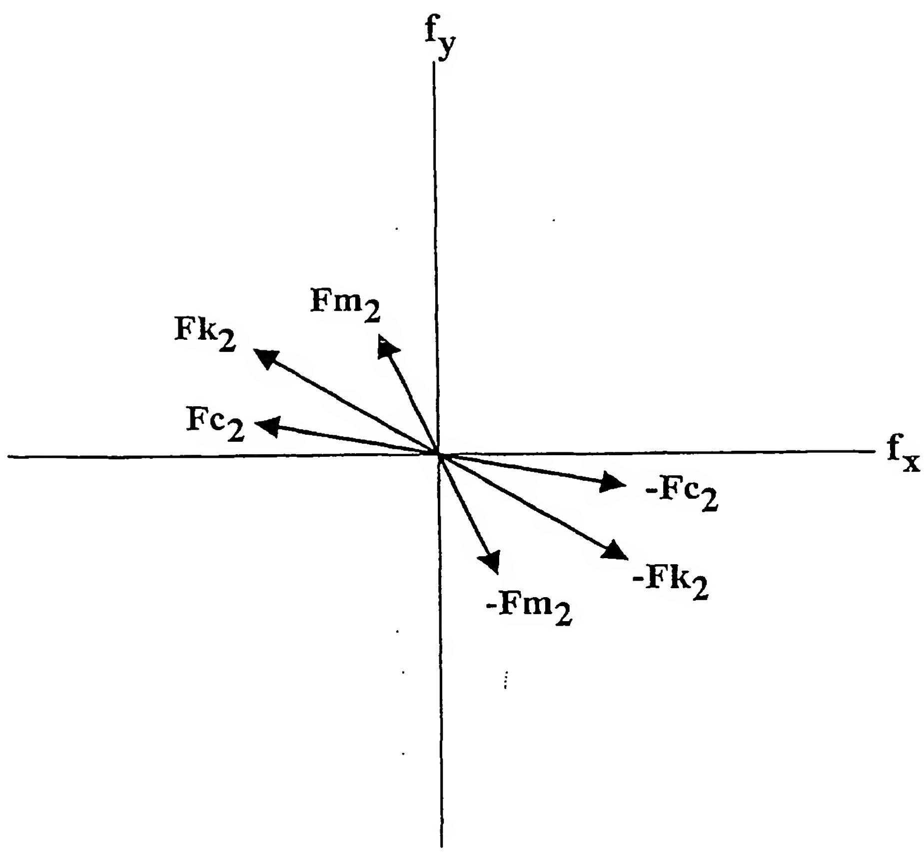

FIG. 9

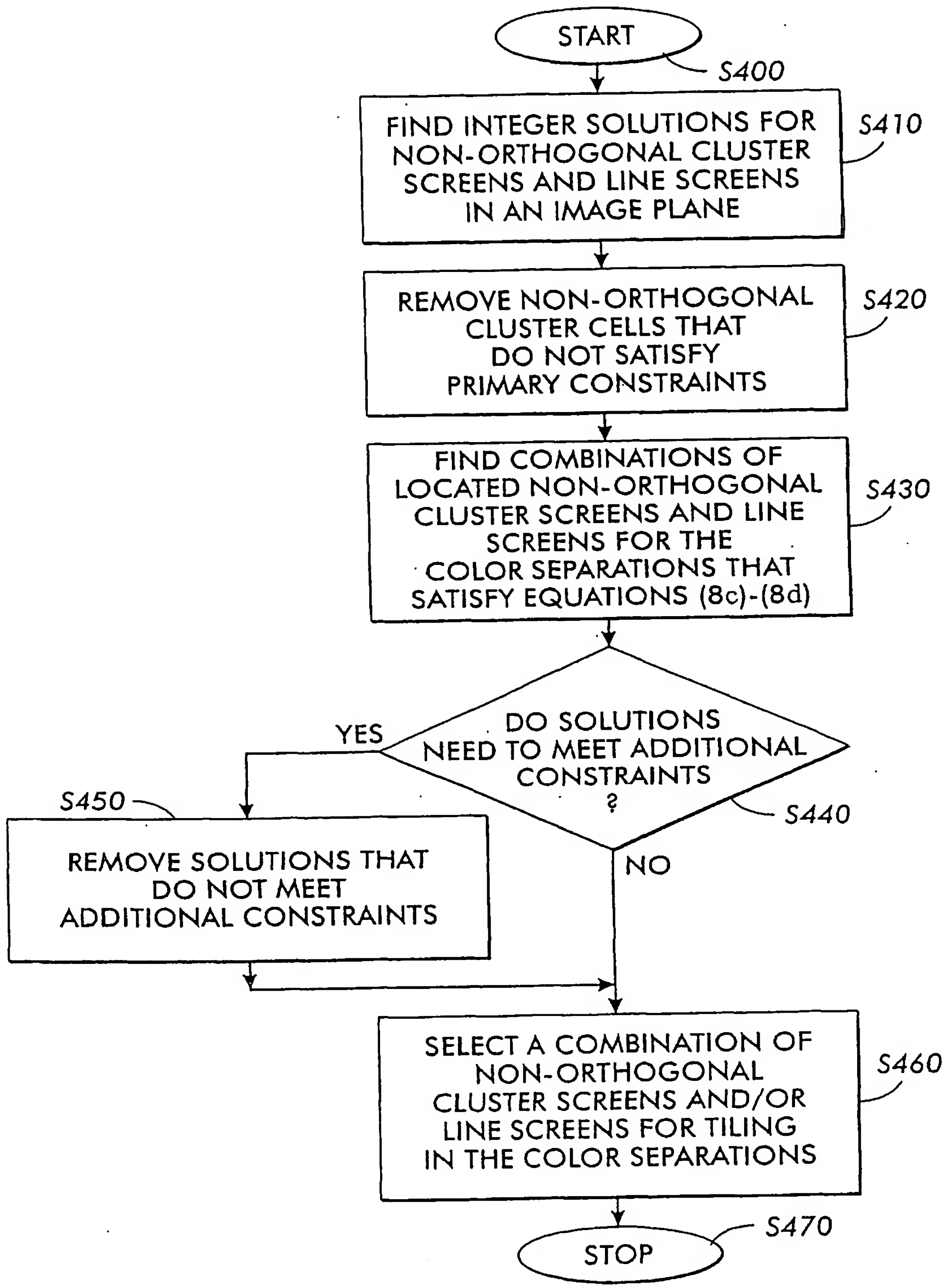
START
S400
FIND INTEGER SOLUTIONS FOR NON-ORTHOGONAL CLUSTER SCREENS AND LINE SCREENS IN AN IMAGE PLANE
S410
REMOVE NON-ORTHOGONAL CLUSTER CELLS THAT DO NOT SATISFY PRIMARY CONSTRAINTS
S420
FIND COMBINATIONS OF LOCATED NON-ORTHOGONAL CLUSTER SCREENS AND LINE SCREENS FOR THE COLOR SEPARATIONS THAT SATISFY EQUATIONS (8c)-(8d)
S430
DO SOLUTIONS NEED TO MEET ADDITIONAL CONSTRAINTS ?
S440
YES
NO
S450
REMOVE SOLUTIONS THAT DO NOT MEET ADDITIONAL CONSTRAINTS
SELECT A COMBINATION OF NON-ORTHOGONAL CLUSTER SCREENS AND/OR LINE SCREENS FOR TILING IN THE COLOR SEPARATIONS
S460
STOP
S470

FIG. 11

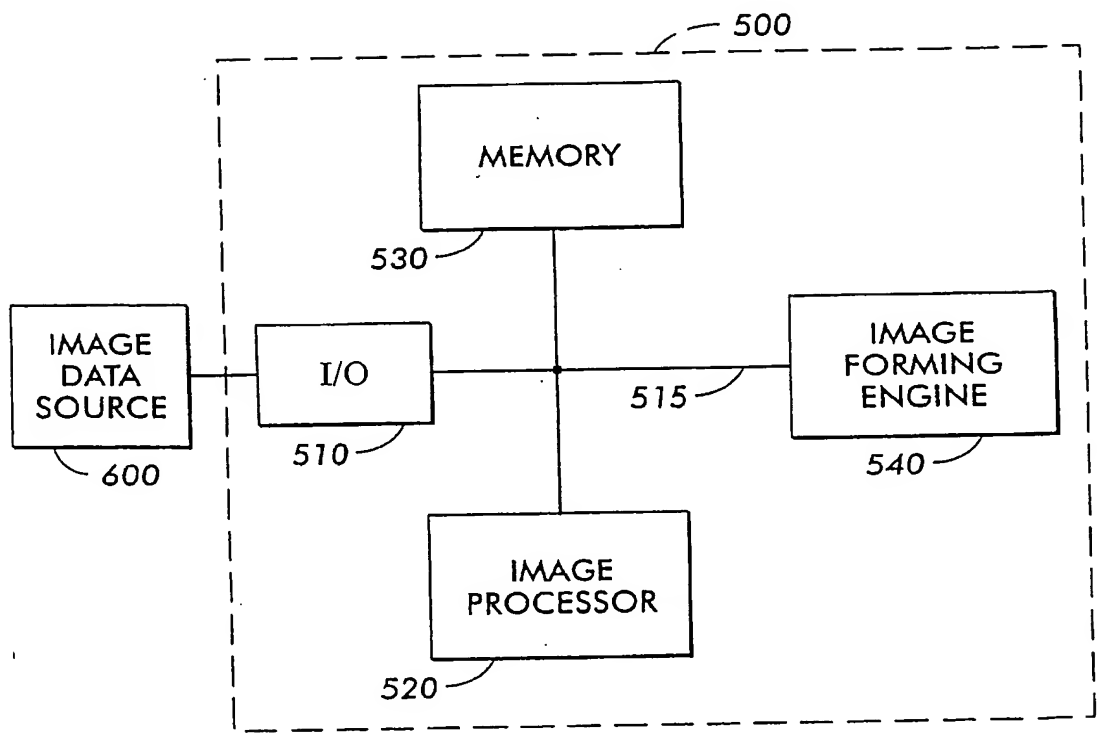
500
MEMORY
530
IMAGE
DATA
SOURCE
I/O
515
IMAGE
FORMING
ENGINE
600
510
540
IMAGE
PROCESSOR
520

FIG. 13